Studies on Sonar Clutter and Reverberation

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LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies
- Characterize acoustic clutter in a manner that will lead to its mitigation
- Improve geo-acoustic parameter extraction from reverberation data
- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect triplet array data from Five Octave Research Array (FORA) and the NURC arrays, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the triplet frequency band (above ~600 Hz) and at lower frequencies.
- Continue the use of K-distribution-based techniques of Abraham [1–3] to statistically characterize the bio-clutter data from FORA.
- Continue validation and improvement efforts on a new reverberation model and investigate physics based clutter modeling.
- Continue work on the automated geo-acoustic parameter extraction technique using reverberation data.
- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, sonar clutter studies and ocean reverberation experiments.

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14. ABSTRACT
The long-term goals of this effort are to ? Assess capability of directional arrays for inversion and reverberation studies ? Characterize acoustic clutter in a manner that will lead to its mitigation ? Improve geo-acoustic parameter extraction from reverberation data ? Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

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APPROACH

There is a 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada. It is called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments are being designed to support the JRP (the Principal Investigator (PI) is a member of this JRP). Recent experimental efforts, called CLUTTER07, took place near the Malta Plateau area in May of 2007 and then a follow-on, CLUTTER09 occurred this past May. It was focused on the physics based and the statistical characterizations of acoustic clutter for lower frequency sonars. The FORA was one of two primary receivers for the CLUTTER07 experiment as well as for the BASE07 sea trial that immediately followed it.

The triplet array section at the head of the FORA offers an improved way to study reverberation and scattering in shallow water. Some FORA triplet data was collected in the 2006 Gulf of Maine experiment near Georges Bank, and a much more extensive set was taken in the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau. In addition, much data has been taken using the NURC array in the same 2007 experiments and in the CLUTTER09 and Boundary 2004 experiments on the Malta Plateau. These data are serving to test and improve the beamforming algorithms and data processing tools needed to better understand reverberation and scattering from towed arrays. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its triplet array (NURC report SR-329A by D. Hughes, [14]). The PI has verified that similar performance was observed using FORA. Studies on wider band beamforming algorithms are a focus of analysis on the 2007 data sets. It well known that often the same reverberation features can be observed over a wide range of frequencies. Objectives for this task are to continue to correlate the high frequency unambiguous feature information from the triplet data with the lower frequency bearing ambiguous information from line arrays and to define the circumstances under which good cross-frequency correlations exist.

The PI completed an initial effort to statistically characterize the clutter seen on STRATAFORM in the 2001 Acoustic Clutter Reconnaissance Experiment (ACRE) using methods developed by Abraham. Results, showed many data segments of matched filtered amplitudes to be non-Rayleigh and that the bistatic data were significantly more non-Rayleigh than the monostatic data. The non-Rayleigh behavior is consistent with the spikiness seen in much of the 2001 ACRE polar displays. Much of the observed statistical differences between various data segments can be explained by considering differences in multipath, amounts of bottom insonification and the overall sound speed structure. Newer work on the 2003 STRATAFORM data showed reverberation there to also be very non-Rayleigh (median shape parameters approximately unchanged from 2001) [9]. However, they had larger average scatterer size, which was consistent with observed fish schools that were more massive than in 2001. This work will be extended to include a statistical characterizations of the fish dominated scattering vs. the bottom-dominated regions to try to discriminate the two different types of clutter.

In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data. So results mapped extracted geo-acoustic parameters only in a spatially averaged sense when reverberation was anisotropic. Assessment has begun on new inversion work using unambiguous triplet reverberation data. However, the expected improvement in inversion quality vs. bearing has so far been offset by SNR issues.

A new faster and simpler range-dependent reverberation model is in ongoing development (together with Dale Ellis of DRDC who is working jointly with the PI) and will serve as the forward model engine for the simulated annealing based inversion scheme already in use. It is expected that refinements to that model will continue under this effort. Examples from the new reverberation model were presented at both the 2006 and 2008 ONR Reverberation Modeling Workshops in Austin, TX and in more detail at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete and at the NURC 2008 clutter symposium.

WORK COMPLETED

Under triplet data analysis a recent paper by the PI presented some directional characteristics of observed clutter and reverberation using triplet arrays [5]. He showed there is usable left right discrimination down to ~600 Hz using the NURC triplet array. Also shown was that the Hughes triplet beamforming algorithm has an upper frequency limitation. In that paper the PI also derived the normalization terms needed to provide calibrated levels out of triplet arrays. More recently the PI has been studying how to improve the Hughes algorithm and has determined that simply expanding the optimum weights term to second order rather than first order destroys the simple linear dependence of the optimum weights on the sines of the roll angles. After conversations with K. LePage at NURC the PI has concluded that the closed form solution for the weights (eq. 8 of Ref 2) should be used to improve performance. This requires a recoding of the algorithm so work is proceeding on that and the revalidation of the new beamformer.

Together with D. Ellis, the P. I. submitted two invited journal articles on our Rapid Environmental Assessment (REA) techniques using reverberation. The articles are a compendium of our joint work from 1996 to 2004 and so we felt it was important to document our efforts in a peer reviewed journal [16,17]. Effort was spent to this past year to answer reviewer comments and submit the final changes.

Efforts to develop a range dependent normal mode based reverberation model (in collaboration with D. Ellis of DRDC) have continued. Westwood’s ORCA [10] is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis’ techniques [11] have been used to build the reverberation model using MATLAB. Results have been submitted (e.g. [6–8]). The most recent efforts have added the time spread and dispersion corrections used by Ellis [11] to the model. The next step will be to implement the adiabatic normal mode formulation for weak range dependent problems. Also as a result of the second ONR reverberation modeling workshop problems 5–11 were redone and resubmitted this past year.

Under this work the PI participated in the planning and execution of the CLUTTER09 sea trial under the Characterizing and Reducing Clutter in Broadband Active Sonar JRP with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada. An additional monostatic set of data was collected by the PI’s involved using the NURC sources and receivers. This was designed to augment the CLUTTER07 data and clarify some of the observations made in 2007.

Also the PI was an organizer for the International Symposium on Underwater Reverberation and Clutter held by NURC in Italy (Sept. 2008). The PI was author or co-author on three papers [18–20].

The PI has also spent some effort in overseeing the ‘care and feeding’ of the ONR FORA at Penn State in preparation for the 2009 PHILEX experiments with M.I.T. including dealing with export controls and shipping issues. Other work included testing the new FORA acquisition computers and understanding and minimizing data latency and synchronization issues in the FORA acquisition

programs. Data are now synchronized to the GPS time base, and GPS time tags have been added to each data block which now make it possible to track data dropouts accurately.

RESULTS

Using the above-mentioned Matlab and ORCA based reverberation model, Figure 1 shows a reverberation vs. time model prediction at 250 Hz for a downward refracting profile and very rough bottom of test prob. 5 from the first ONR Reverberation Modeling Workshop. Also shown for comparison is a prediction for Problem 11, an isovelocity Lambert's rule case using the NOGRP model of Ellis. Figure 2 shows a similar reverberation vs. time model prediction at 250 Hz for a downward refracting profile but using a moderately rough bottom of test prob. 5 from the first ONR Reverberation Modeling Workshop. One can see the obvious drop in predicted reverberation levels from Fig. 1 to Fig. 2 as expected. Both these results were shown to agree quite well with the other participants' results after about 1 s. Earlier than that this trapped mode (real axis modes) model can't do a proper job of modeling the near term energy. The PI plans to use the full complex plane solutions from ORCA to look at near term arrivals to try and improve the estimation in that region.

Several improvements were made to the FORA acquisition system (by Programmer G, Ruhlmann). Many small coding errors were corrected last February. Among the most important was the ability to accurately estimate one-way time travel. Previous timing errors were found and corrected. To test it we measured time of arrival of impulses from a pinger system designed by K. von der Heydt of Woods Hole Oceanographic Institute (WHOI) that was attached directly to the FORA. We found a nearly consistent latency of 8 ms ±0.1 ms for the 8 kHz sampling configuration of FORA. In the NPAL 2004 experiment there were errors of at least 0.5 s with no way of correcting them. (This problem has no effect on LFAS experiments because zero time reference starts at the direct arrival of each ping).

In the course of improving the FORA acquisition system for the PHILEX09 experiment GPS time tags have been added for each data block. As a result, E. Scheer of WHOI was able to check that each data block was written at the same delta time (0.256 s in this case). But he observed that sometimes the delta time was off by 10–30 ms (which he calls 'small glitches'). There were a total of 350 of these small glitches over the course of the experiment out of 281 hours of FORA data collected.

Figure 3 shows the cumulative error count of FORA glitches from the PHILEX09 experiment. The top shows 'large glitches' due to loss of GPS signal but no data loss (not serious). The bottom portion shows 'small glitches' vs. day of experiment. The vast majority of these glitches occurred in the three large jumps near days 107, 110 and 112. These correspond to two days where wind speeds exceeded 30 knots and the one near day 110 where a salt water short occurred in the aft array module. (Graph is courtesy of E. Scheer of WHOI).

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC triplet arrays are exciting new tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates. Improvements made to the FORA acquisition system have made one-way travel time measurements much more accurate. Time tagging the data blocks has made it possible to find data dropouts for the first time with FORA.

The CLUTTER09, CLUTTER07 and BASE07 experiments on the Malta Plateau have produced a large quantity of high quality data that will help ONR researchers to understand and eventually mitigate sonar clutter.

TRANSITIONS

Inversion techniques similar to those described above have been applied to select data from recent HEP experiments as part of ONR 6.2 efforts led by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

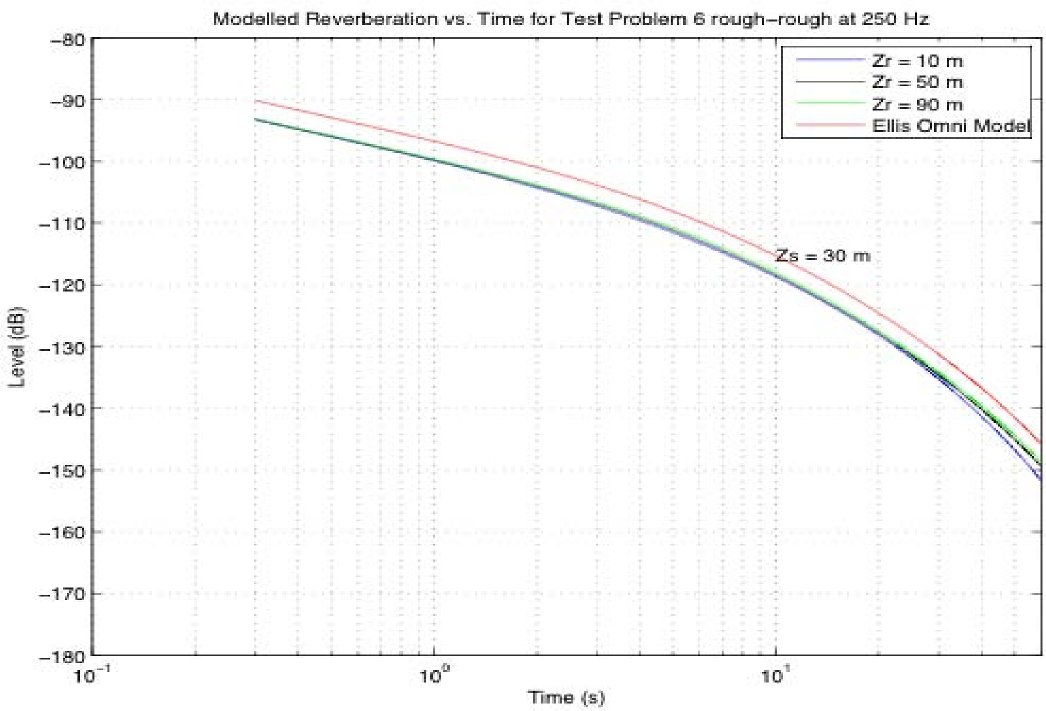

Fig.1. Reverberation model prediction for a downward refracting profile and very rough bottom of test prob. 5 from the first ONR Reverberation Modeling Workshop.

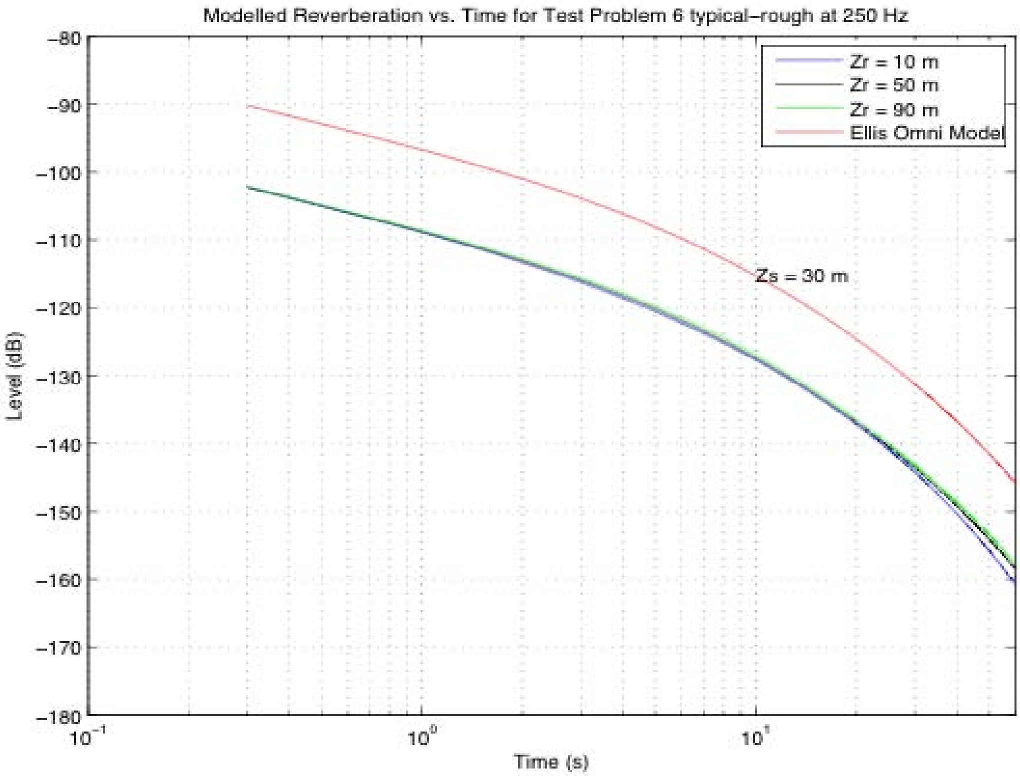

Fig.2. Reverberation model prediction for a downward refracting profile and moderately rough bottom of test prob. 5 from the first ONR Reverberation Modeling Workshop.

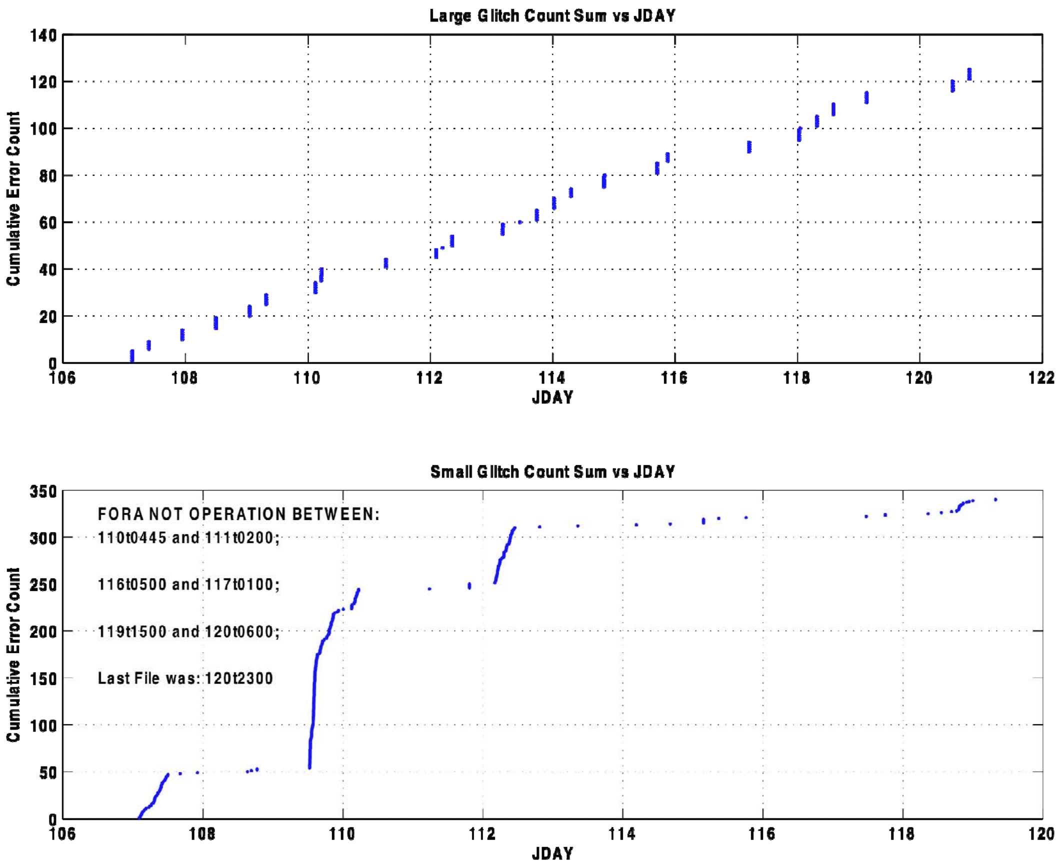

Fig. 3. Cumulative error count of FORA 'glitches' from the PHILEX09 experiment. Top shows 'large glitches' due to loss of GPS signal but no data loss. Bottom shows 'small glitches' typically 10 - 30 ms of data lost vs. day of experiment. Three large jumps near days 107, 110 and 112 correspond to two days where wind speeds exceeded 30 knots and near day 110 a short occurred in the aft array module. (Graph courtesy of E. Scheer of Woods Hole Oceanographic Institute).

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